

A Comprehensive Review of the Tests Completed on the Flowloop at the Energy Systems Laboratory

Jay Robinson

Introduction

In 1988 the Governor's Energy Office (GEO) of Texas received approval from the U.S. Department of Energy to establish a \$98.6 million state-wide retrofit demonstration program, the LoanSTAR (Loan to Save Taxes and Resources) Program. The LoanSTAR Program was designed to demonstrate commercially available, energy efficient, retrofit technologies and techniques. Part of the approved DOE program includes monitoring buildings to determine the effectiveness of the retrofits. The monitoring for this program is composed of thermal metering (chilled and hot water Btu measurements), electrical load metering, psychrometric data (cooling and heating coil temperatures and humidities), and weather monitoring. All of the sensors and monitoring equipment must be calibrated prior to installation and recalibrated periodically while in service. For this purpose, a calibration facility was developed in which National Institute of Standards and Technology (NIST)-traceable instrumentation is maintained (Turner et al. 1992).

This paper discusses the progress and accomplishments of the flowloop calibration facility since its inception. A chronological history of the facility is presented along with results from each stage of testing. The paper is organized in major sections according to the test section pipe size and the type of metering tested.

SECTION I

General Overview

The majority of the analysis work done in the LoanSTAR project originates with the data taken in the field by the various types of monitoring equipment. Therefore, it is important to have monitoring equipment that is accurate and reliable. Initial calibration and periodic re-calibration of the equipment is the best way to ensure field accuracy. The calibration laboratory was built to provide a close at hand facility where the majority of this work could be performed. The flowloop was built to provide a means of calibrating the thermal monitoring equipment such as the flow meters and the Btu transducers.

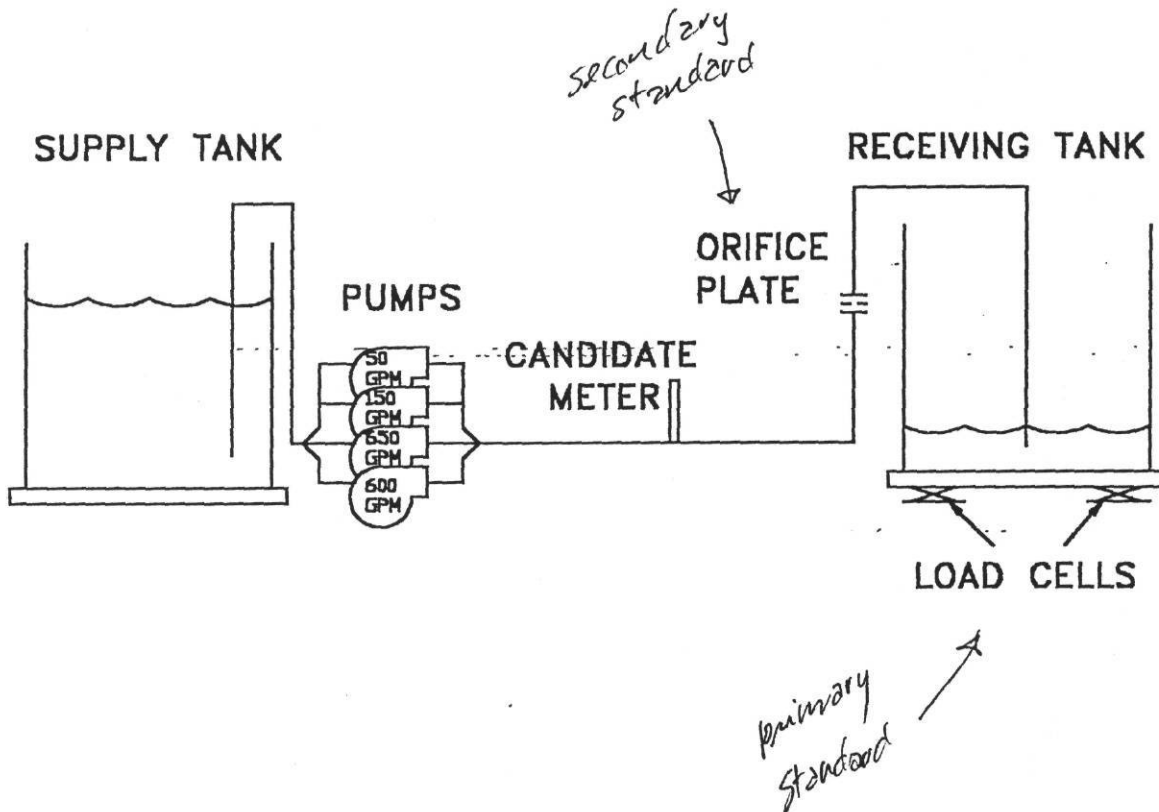
The first task of the facility was to determine the overall performance characteristics of the different types of flow meters being used in the project. This was done by testing typical meters in a range of pipe sizes. The second task is to be able to test the flow meters upon removal from the field to determine if there has been any degradation in performance since their installation. Ultimately, the flowloop facility should be able to take on outside calibration projects and become an independently functioning facility.

Description of the Flowloop Facility

The flowloop is designed compare the flow rate from a candidate sensor to the flow rate determined by the laboratory standard. A diagram of the flowloop is given in Figure 1. The loop consists of two 10,000 gallon tanks, a series of four supply pumps, a test section and a return line and pump. The receiving tank platform rests on four symmetrically placed strain-bridge load cells. The dynamic weight of the water is measured over time by summing the signal from the four load cells and processing that signal with the water temperature to determine a volumetric flow rate. The test section holding the candidate meter links the two tanks and a perforated plate type flow straightener (Miller 1989) is installed at the supply end of this section to ensure fully developed flow. Various flow rates are achieved by using combinations of four of the pumps located at the supply end of the test section. The minimum volumetric flow rate is 30 gpm and the maximum is 1200 gpm. When tests are run at the maximum flow rate, they can extend no longer than 8 minutes before the supply tank runs out of water. The test section is removable and pipe sizes of 4", 6", 8" and 10" are available for installation and testing. Following each test, the water is pumped through a return line from the receiving tank back to the supply tank.

An orifice plate assembly has been installed to provide a secondary standard. The orifice plate is located in the vertical rise between the test section and the receiving tank. A differential pressure transducer with a 0-250 in. H₂O range is used to measure the pressure drop across the orifice. Since a wide range of velocities are used during testing, any one of five orifice plates with different bore sizes can be inserted between the flanges to keep the pressure drop within the range of the transducer. Prior to the installation of the secondary standard, an ultrasonic flow meter was used in the test section to provide a check against the load cells.

Figure 1: *Diagram of the liquid flowloop Calibration Facility.* This figure is a diagram of the flowloop used to calibrate flow sensors. Water at varying flow velocities is drawn from the supply tank, pumped through the test section and diffused into the receiving tank. The changing weight of the water is measured to determine the flow rate for comparison with the candidate sensor.



The electronic signals from the load cells, candidate meter, ultrasonic meter, differential pressure transducer and temperature probe are converted into digital data through the use of a data acquisition system and a PC-based desktop computer. Figure 2 shows a schematic of the data processing. The signals from the load cells, orifice plate and candidate meter are displayed in real time during the testing to alert the operator of any malfunctions during the test. On several occasions, unusual behavior such as a drop in the velocity has been identified during the test thus allowing immediate correction of the problem.

Test Procedure

The test procedure changes in accordance with the type of meter being examined. The general test procedure is as follows. The candidate meter is installed in the test section according to the specifications for the test. All of the data channels desired for the particular test are connected to the data logger. Typically the load cell signal, water temperature, differential pressure from the orifice plate, and candidate meter signal are always recorded. Optional channels specific to each test such as raw pulses from the flow meter, Btu signals from the Btu meter, and totalized channels that sum different signals can be added if desired.

Once the datalogger is ready, the isolation valves on the pumps that are not being used are closed to prevent water from being drawn through an inactive pump and the control valve is set for the particular velocity of that test. The pumps are started and a few seconds later, the logger is started. Tests usually are five minutes in length with data being taken at 5 second intervals. This produces approximately 55 datapoints for analysis. Tests for the first few months were run for 10 minutes, but it was determined that 5 minutes was sufficient and would allow for more rapid testing.

The raw data is brought into a template in a spreadsheet for processing. A calculation is performed on the load cell velocity to correct for the change in the density of the water due to the temperature. The orifice plate velocity is calculated from the differential pressure and several other calculations are performed to aide in the presentation of the data. The averages for each of the sensors are calculated over the entire test along with the standard deviations and coefficients of variance. These averages are then put into a summary sheet as a single data point. An example of these points is presented in Table 1.

Figure 2: Schematic diagram of the datalogging procedure for the liquid flowloop. All of the analog and digital signals from the equipment being monitored are directed to the datalogger.

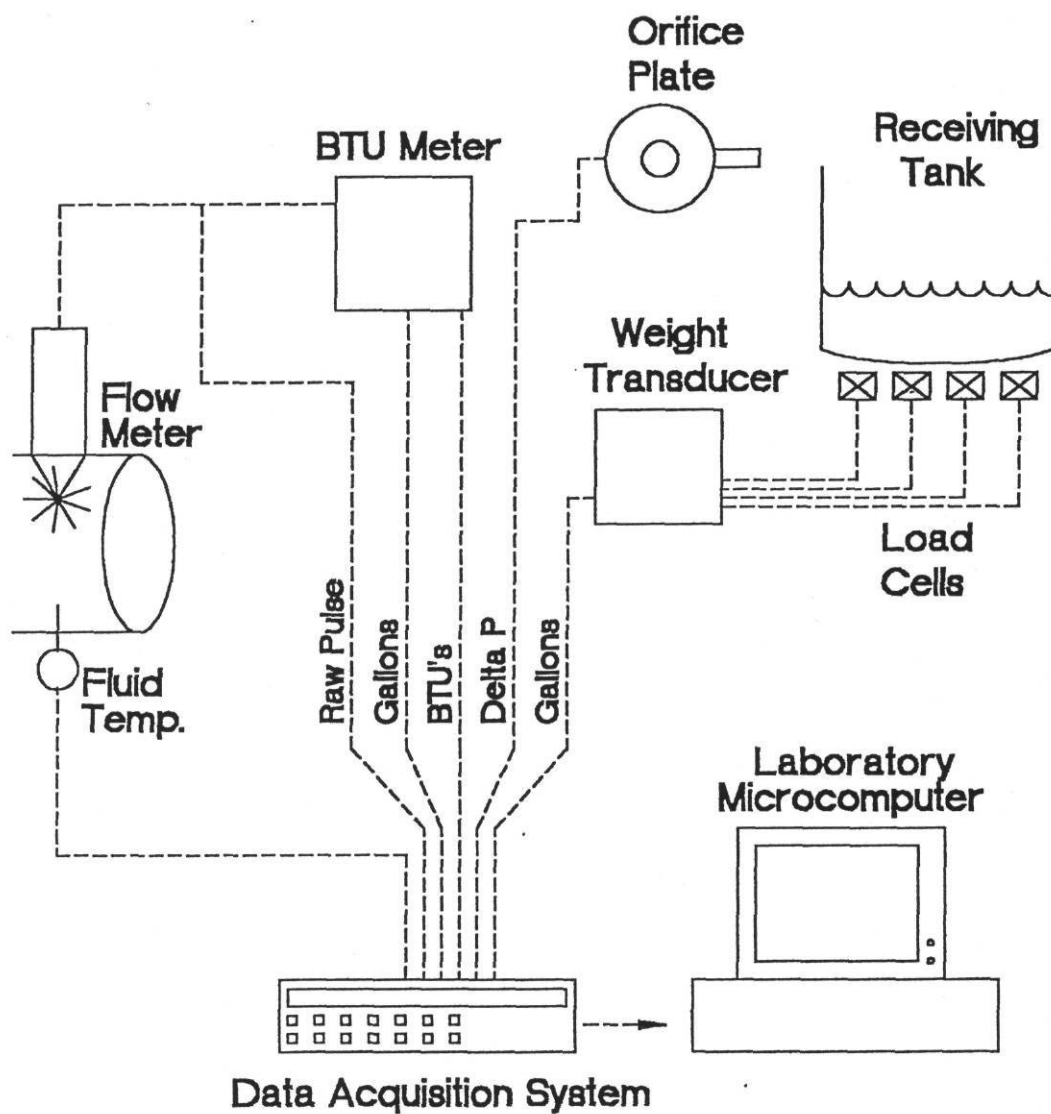


Table 1: Flow Velocities From a Test of Paddlewheel and Orifice Plates vs Load Cells. This table contains data taken from a test of a non-magnetic tangential paddlewheel flow meter. The meter was inserted at the manufacturers recommended depth of 1.5" into the flow stream of an 8" pipe. A PPG factor of 15 was used in this test as published by the manufacturer for these flow conditions. The PPG factor in column 7 is empirically derived during testing for comparison purposes.

Load Cells	Load Cells	Orifice Plate	Orifice Plate	Paddle-wheel	Paddle-wheel	PPG Factor	Reynolds Number
Velocity (ft/s)	CV= Sdev/Vel.	Velocity (ft/s)	CV= Sdev/Vel.	Velocity (ft/s)	CV= Sdev/Vel.	Empirically Derived	8" Pipe
0.269	10.98%	0.266	0.20%	*0.168	188%	9.1	20,900
0.463	8.66%	0.469	1.32%	*0.413	92%	13.4	35,900
0.502	5.78%	0.494	0.30%	*0.452	82%	13.2	38,900
0.592	5.62%	0.583	0.30%	*0.530	66%	13.7	45,900
1.314	4.57%	1.270	0.30%	1.305	26%	14.8	101,900
1.730	3.78%	1.696	0.60%	1.679	18%	14.5	134,200
2.127	1.42%	2.129	1.07%	2.067	17%	14.5	171,900
2.897	3.82%	2.868	1.12%	2.803	13%	14.5	224,700
3.344	3.72%	3.318	1.23%	3.294	11%	14.8	259,300
4.672	3.95%	4.654	1.60%	4.767	8%	15.3	362,300
5.838	4.43%	5.834	2.53%	5.933	6%	15.2	452,700
6.927	5.27%	**	**	7.107	7%	15.4	537,200
7.722	6.26%	**	**	7.971	8%	15.5	598,800

NOTE:

(*) While the paddlewheel did function at these flow rates, they are below those recommended by the manufacturer

(**) The flow rates are out of the range of the current orifice plate configuration.

(+) The Reynolds number was calculated using load cell data.

SECTION II

6" Test Section

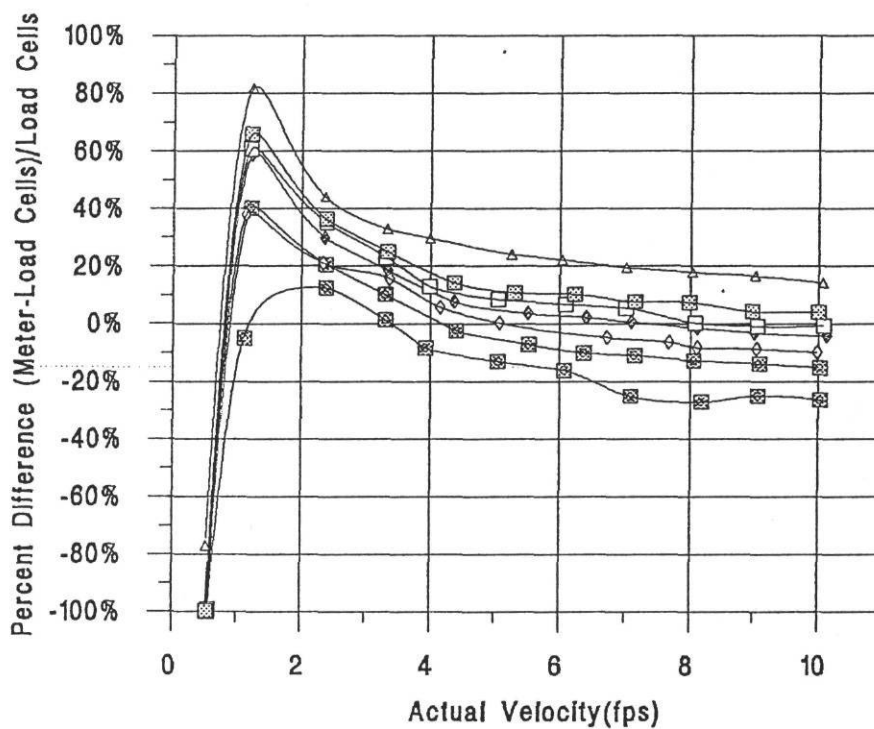
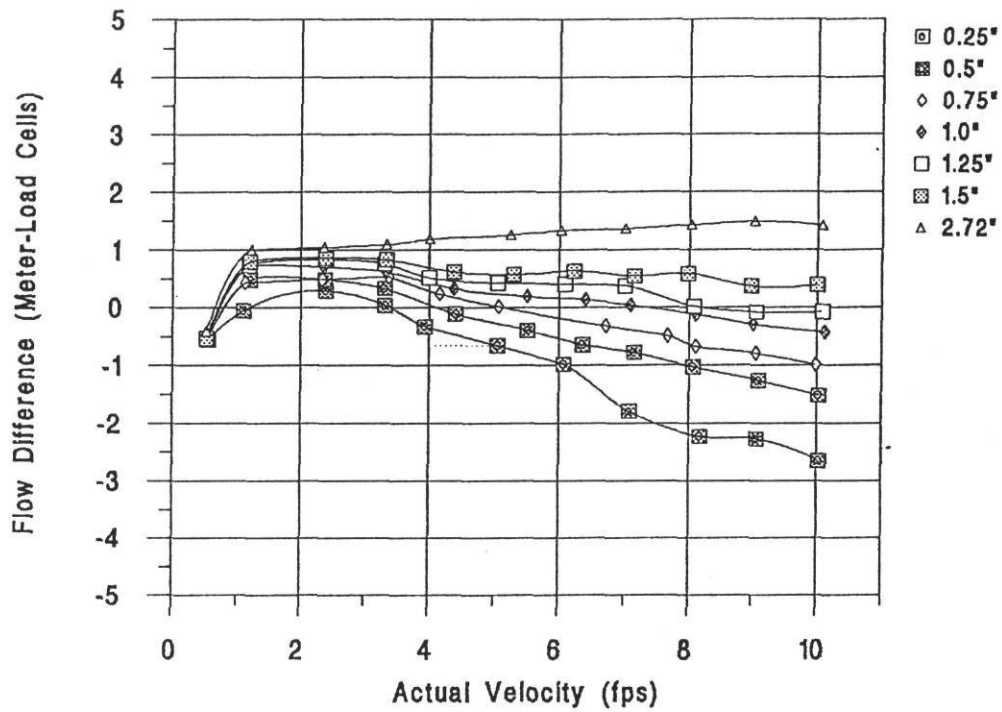
The 6" test section was the first section used in the flowloop. All of the preliminary tests and initial trials were conducted in this section. As with any new project, it took several months to develop a definite method for conducting the tests. The first few months of operation were dedicated entirely to initialization of the facility. Frequent problems arose with output signals from some of the equipment and with the communication between the data acquisition system and the sensors. Once all of these problems were addressed and solved, the first stages of testing began.

The first meter tested was a tangential paddlewheel meter that uses magnets in the paddlewheel to generate a mV sine wave signal. The flow signal was processed through a signal conditioner provided by the manufacturer which translated it into a 4-20 mA output. This 4-20 mA output was proportional to a flow rate in fps and was recorded with the data acquisition system and compared to the flow rate from the Load Cells.

In field installations, it is sometimes difficult to make all of the necessary measurements to ensure that the meter is inserted at the proper depth in the pipe. Therefore, one of the first tests performed tested the effect on the results of changing the insertion depth of the meter. The meter was tested at depths ranging from 1/4" to 1.5" on 1/4" intervals. The recommended depth from the manufacturer for this meter in 6" pipe is 3/4". A summary graph of the results is presented in Figure 3. This data shows that the meter inserted at centerline registers a flow rate higher than the actual velocity while a meter inserted close to the wall (0.25" ID) registers a flow rate lower than the actual velocity. This is the expected result because in a round pipe, the local velocity at the centerline of the pipe will be higher than the local velocity near the wall.

After several months of testing the insertion depth, a change in the method used to process the flow signal was made. In the field installations, the flow meter is used in conjunction with the temperature to determine the Btu usage of the installation. A thermal energy transducer (Btu meter) accepts the raw mV signal from the flow meter. It counts each peak from the mV sine wave signal generated by the meter as a pulse. The Btu meter acts as a counter, recording each pulse that it receives from the flow meter. A pulse per gallon (PPG) factor is set in the Btu meter and when the number of pulses received from the flow meter equals the PPG factor in the Btu meter, a gallon is recorded. This setup does not

Figure 3: Results from insertion depth test in 6" pipe. These results show the performance of the magnetic meter over varying insertion depths in 6" pipe.



require the signal conditioner that gives out the 4-20 mA output. In order to duplicate the field installations as much as possible in the lab tests, a Btu meter was installed in place of the signal conditioner. The raw signal from the flow meter was connected to the Btu meter. The raw signal from the flow meter and the gallon output from the Btu meter were recorded with the data logger.

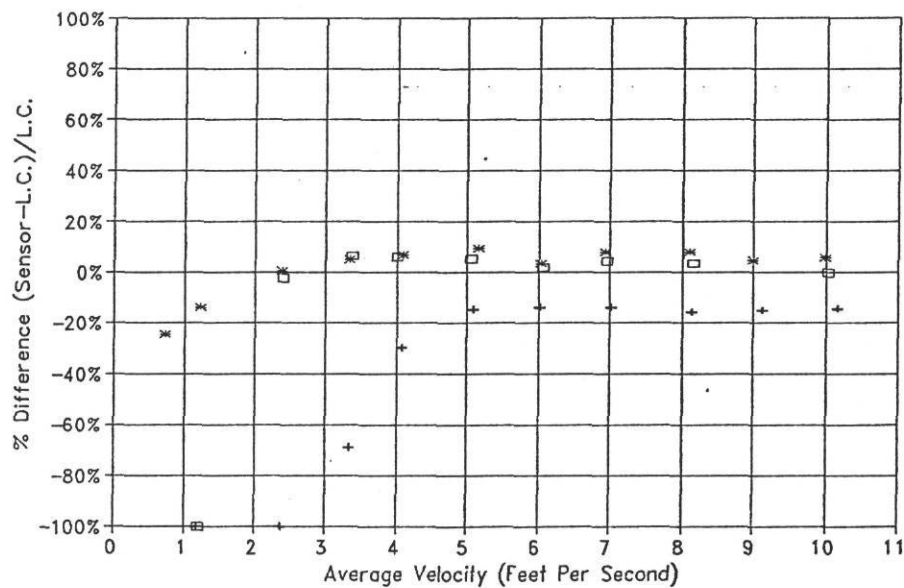
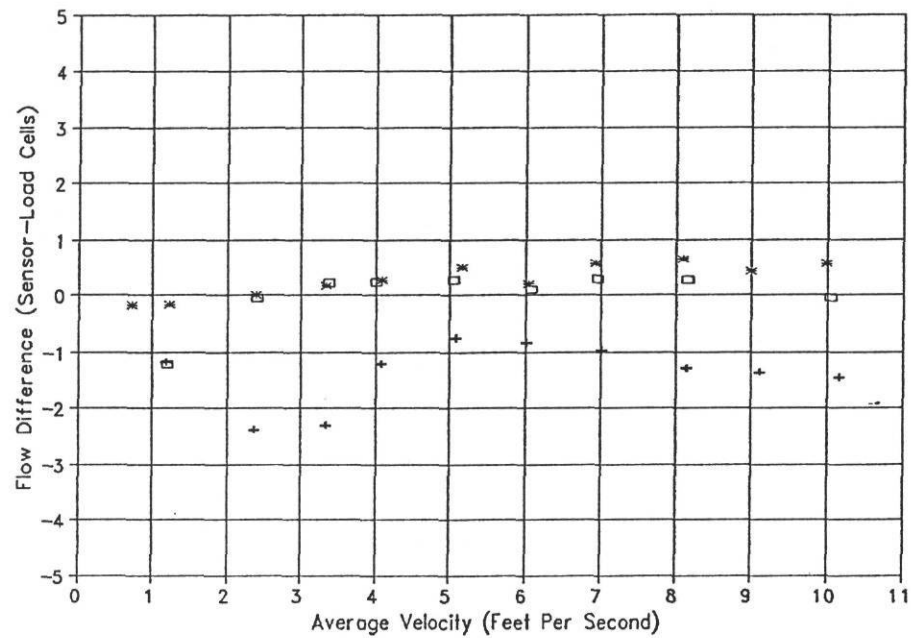
Tests using this new combination were completed with two significant results which are presented in Figure 4. First, the flow rate recorded by the flow meter was on average 15% lower than flow rate shown by the load cells. Second, the Btu meter failed to record flow rates below 4 fps. The fact that the flow rate was 15% low brought all of the thermal data recorded from the sites since the inception of the project into question. Secondly, the failure of the system at low flow rates was significant because many installations have low flow rates or have periods of operation when the flow rates drop into this flow range.

It was quickly determined that the 15% difference could be easily corrected. The flow meter was working correctly, but the flow signal was being scaled incorrectly. By recording the raw pulse signal from the flow meter as mentioned above and the number of gallons recorded by the load cells, an empirical pulse per gallon factor is derived. After considerable testing over the range of flow rates, a new pulse per gallon factor was calculated. Re-testing the meter with this new factor entered into the Btu meter brought much better results with the flow meter recording $\pm 5\%$ of the flow rate. In addition, testing the original and subsequent meters with the new PPG factor showed the low end threshold to be 2 fps rather than 4 fps as seen originally.

The problem of the low flow rates was not as easily solved. Close observance of the meter showed that it was still rotating and producing a signal at velocities below 2 fps. However, the signal became weaker as the flow rate dropped. A signal with strength of at least 15 mV from the flow meter is required for the Btu meter. Below 2 fps, the signal from the flow meter was below this threshold. In order to correct this problem, a pre-amplifier was developed to take the flow meter signal and amplify it to the necessary strength for the Btu meter. This solution worked very well in laboratory tests, allowing flow rates to be measured down to 0.8 fps. However, upon field implementation, the pre-amp proved to be difficult to install and had a tendency to pick up background noise and amplify it. The unresolved difficulty of the low flow problems led to the selection of a second meter using different electronics technology.

what type
of background
noise?
Can it be shielded?
or filtered

Figure 4: Test results from the 6" pipe. These results show the performance of the magnetic and non-magnetic meters with the manufacturer's pulse per gallon (PPG) factor and with the experimentally derived PPG factor.



* Non-magnetic Meter + Magnetic Meter □ Mag Meter Corrected

A series of tests was performed in which the rotation of the meter was changed as seen in Figure 5. This test had two purposes. First, there are several instances in the field where the flow meters cannot be inserted in the vertical position. It was desired to see what effect if any, this had on the flow results. Secondly, the test would show if there were any inconsistent flow patterns in the flowloop such as swirling flow. The results of this test presented in Figure 6, show no measurable difference in the flow velocities recorded between the rotated meters and the vertical meter. In all three tests, the candidate meter recorded velocities within 5% of the standard velocity. These results indicate that the initial accuracy of the meters in the field is not greatly affected by the angle of insertion. They do not however, indicate that installation angle of the meters should be ignored. While there are installations where vertical installation is not possible, the manufacturers insertion instructions should be followed whenever possible as improper installation might have an adverse effect on the wear of the meter thus affecting the long-term results.

As mentioned above, the difficulty with the magnetic meter in low flow applications led to the use of a new meter. A non-magnetic tangential insertion paddlewheel meter was acquired for testing. This meter works on a different principal than the signal generating magnetic meter. A constant voltage is sent to the meter and an electric field is produced across the paddlewheel. As the paddlewheel rotates, the blades break this field causing a break in the signal. This break is seen by the Btu meter as a pulse. The flow meter will function as long as the velocity of the water is high enough to turn the paddlewheel. Figure 7 shows the difference between the magnetic and non-magnetic signals. The results of this test which are presented in Figure 4, are very good. The meter performed to within $\pm 5\%$ of the flow rate for velocities ranging from 1 to 10 fps.

The final set of tests run in the 6" test section used the magnetic flow meter in conjunction with a different Btu meter. Since the second Btu meter used the same PPG factor as the first, no difference was expected. Test results presented in Figure 8 compare the performance of the two meters. The average percent difference for Meter #1 as mentioned above was -15% of the flow rate. The average percent difference for Meter #2 was -11.5% of the flow rate. The difference between the two meters is not very significant, however, the meters did not perform identically as expected. Since both manufacturers use the same PPG factor provided by the flow meter manufacturer, it is unusual that they produce different results. The only explanation for this is that there may be a difference in the signal

Figure 5: *Cross section of the test section showing the rotation of the flow meter. The meter was rotated through 60 and 130 degrees from the vertical.*

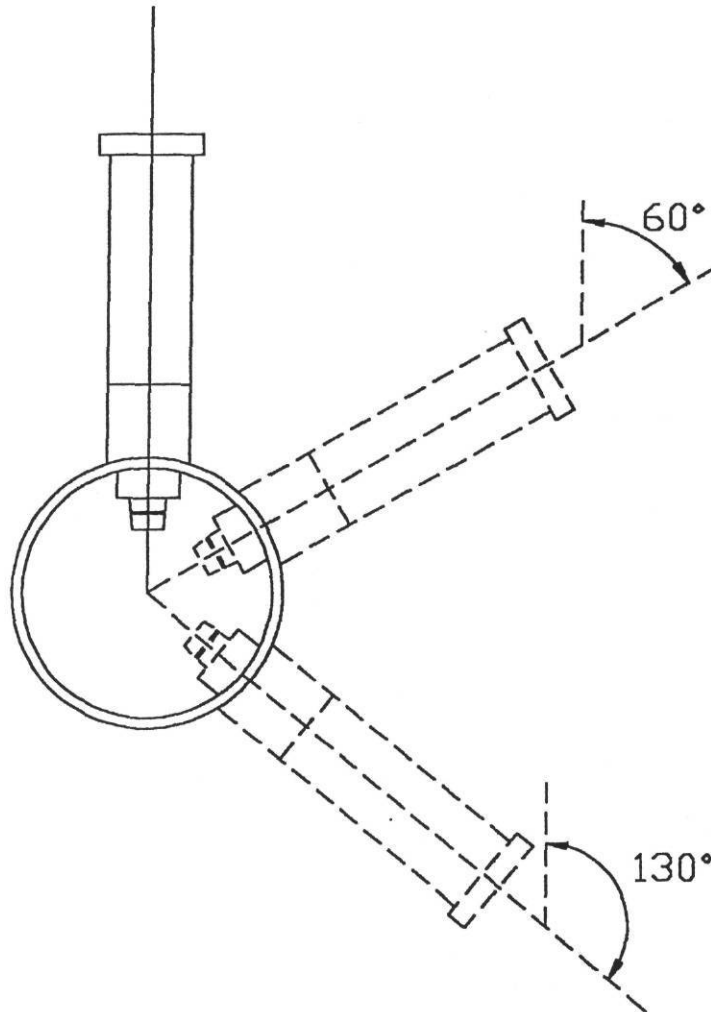


Figure 6: *Results from the rotation of the meter in the 6" pipe.* These results show the performance of the magnetic meter after it was rotated through 60 and 130 degrees of vertical. The PPG factor used in these tests was experimentally derived in the laboratory.

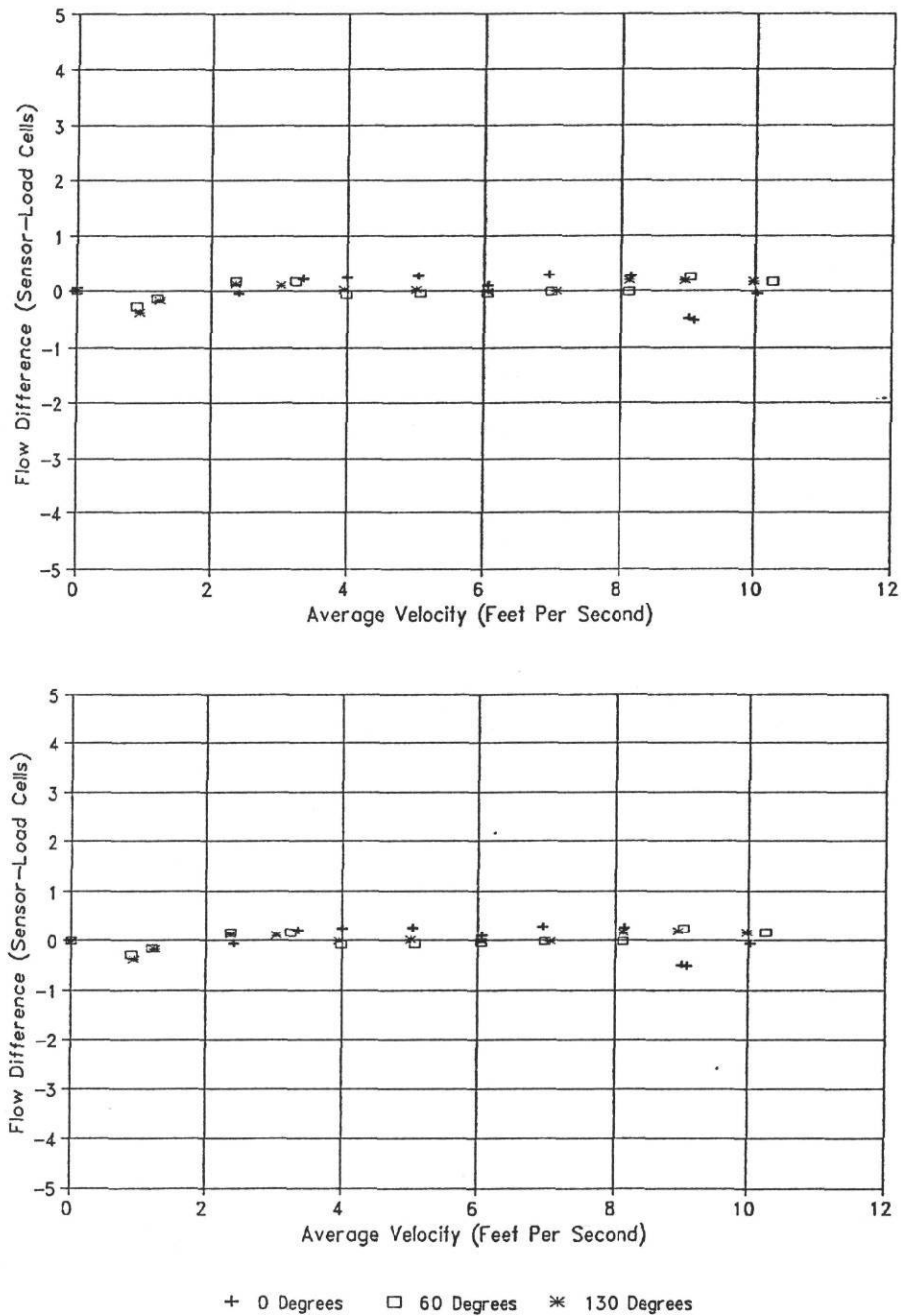
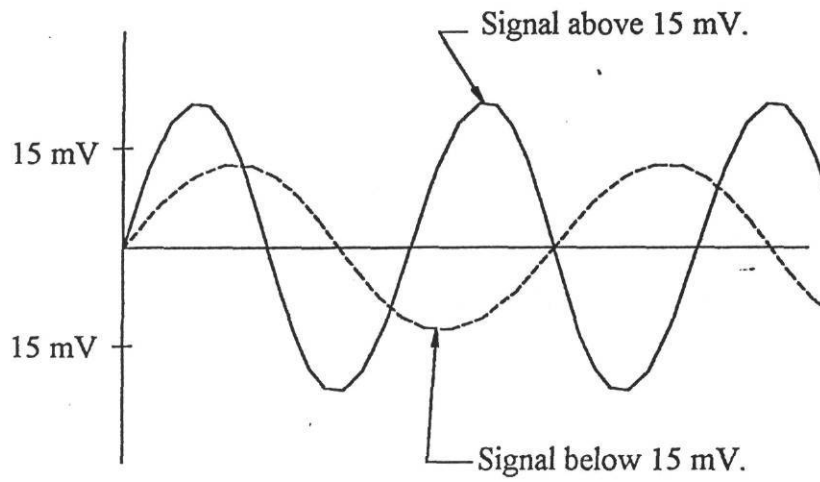
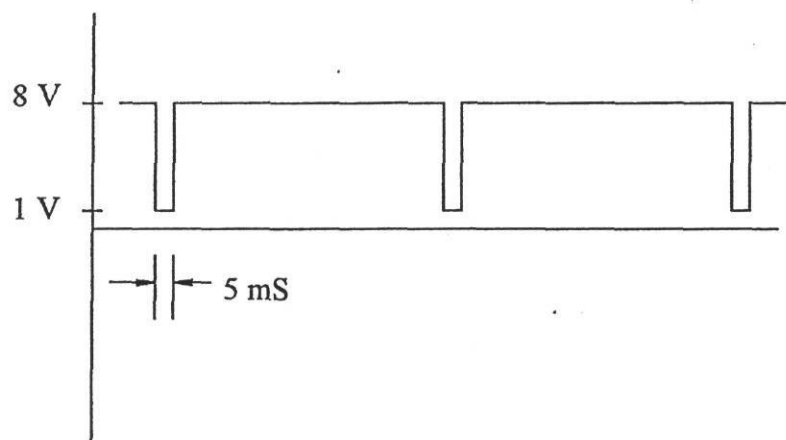


Figure 7: Signals produced by the (a) magnetic and (b) non-magnetic flow meters.

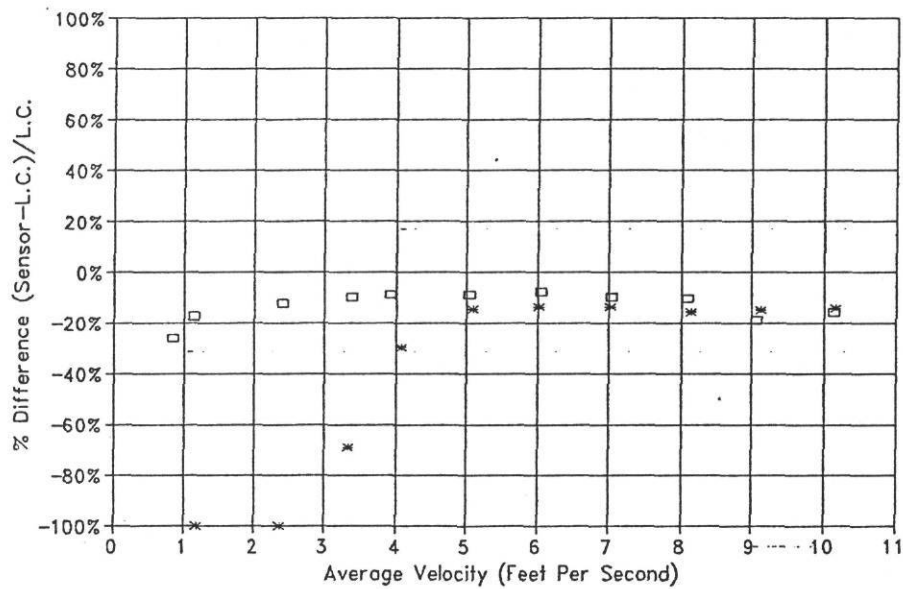
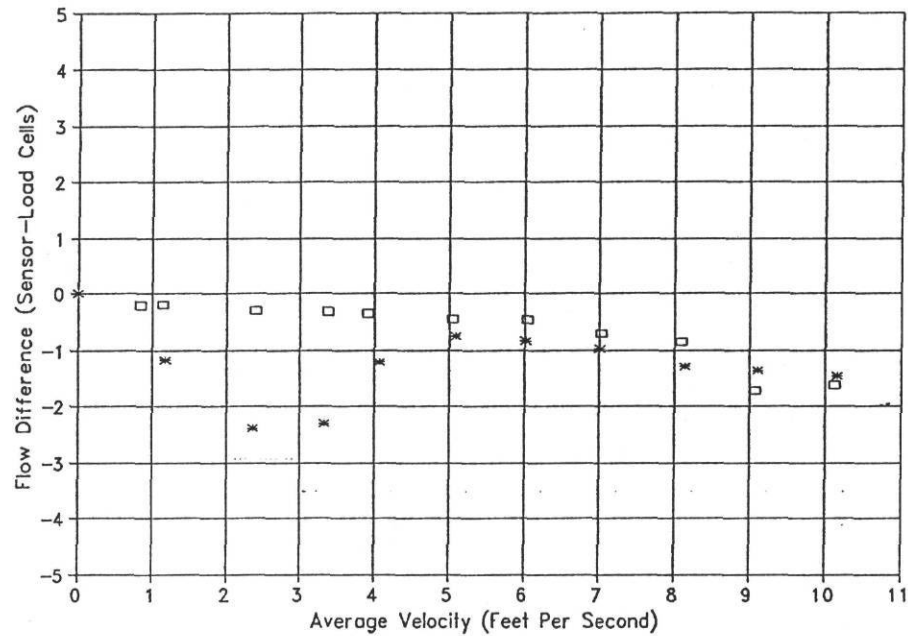


(a)



(b)

Figure 8: *Test results from the second type of thermal energy transducer in 6" pipe.*
These results show the performance of the magnetic meter using a second type of Btu meter.



* Btu Meter #1 □ Btu Meter #2

processing between the two manufacturers. Two other observations of interest were made during these tests. First, the gallon resolution for the second Btu meter was 200 gallons whereas the first meter could be scaled at 1, 10, or 100 gallons. Over the long term, this is not significant, however, when the data is being polled every hour in a low flow situation, the results might be misleading. If at the point in time when the logger reads the Btu meter, 180 gallons have been recorded, the Btu meter would register zero. While sooner or later, the results will even out, they can be greatly distorted when considered at point intervals. Also, the PPG factor on these meters is not field scalable. If it is desired to change the meter from a 6" pipe to an 8" pipe, the unit must be returned to the factory and adjusted. Finally, the second Btu meter had a much lower velocity threshold with the magnetic meter. As seen in Figure 8, the first meter did not perform below 4 fps in the 6" pipe while the second Btu meter continued operating down to 1 fps. Apparently, it has the capability of reading a weaker mV signal from the flowmeter. While this is a significant factor it is not enough to override the advantages of the first meter. The gallon resolution and more importantly, the field scalability are more advantageous to the monitoring project in the long run. Thus, with a few exceptions, the first type of Btu meter is used in most instances.

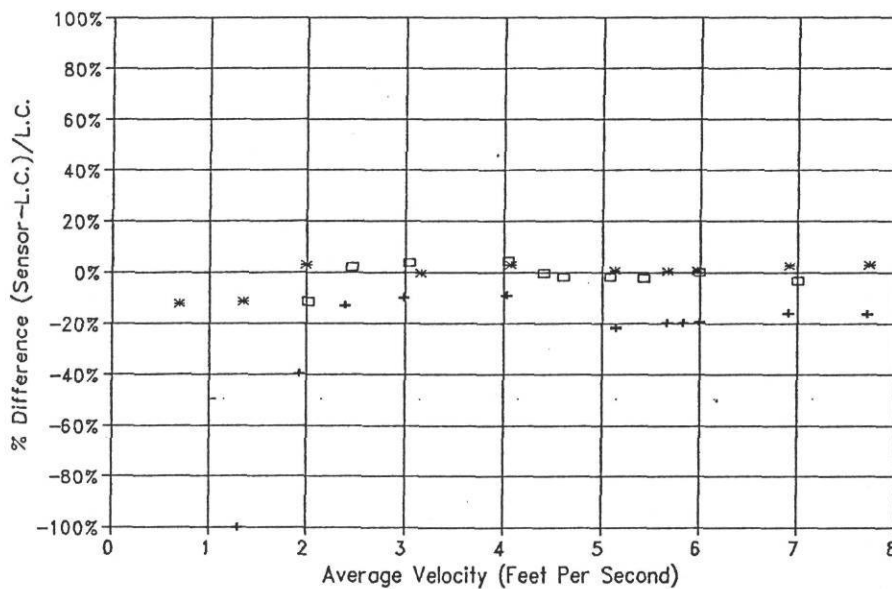
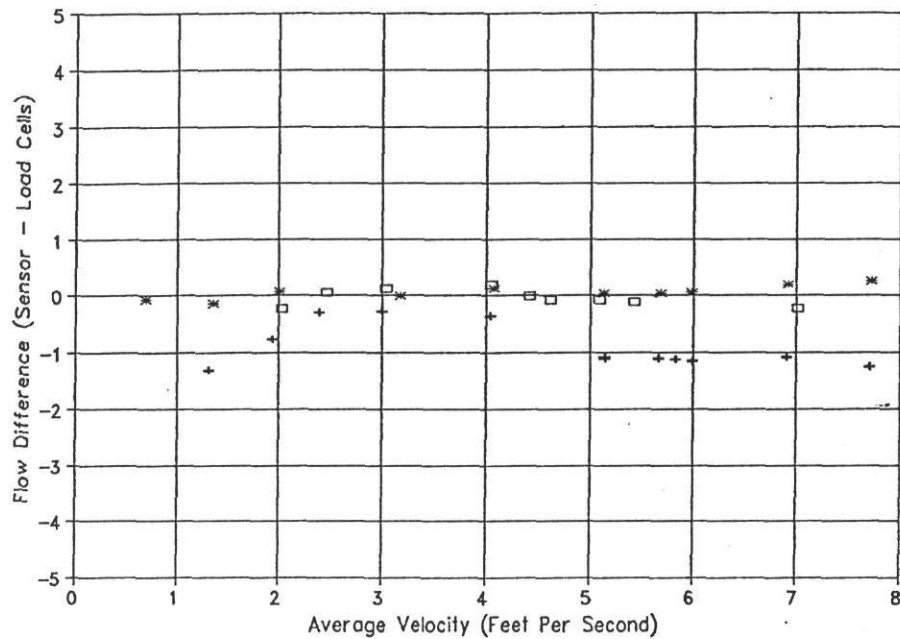
SECTION III

8" Test Section

The 8" test section was installed and testing done for both the magnetic and non-magnetic meters. The first round of tests with the magnetic meter presented in Figure 9 showed that it was 15% lower on average than the load cell reading. A new PPG factor was determined and tested and the results were very good. With the new factor, the magnetic meter was $\pm 5\%$ of the given flow rate for velocities above 2 fps. The same problem with the low flow that was observed in the 6" pipe was present here as well. However, the low flow threshold of the 8" pipe was a little lower than that of the 6" pipe.

The non-magnetic meter was also tested in this 8" section and the results were again very good. As seen in Figure 9, the meter performed within $\pm 5\%$ of the flow rate for all velocities above 1 fps, and was within 10% of the flow rate at 0.5 fps. In addition to the standard testing, a series was run with the meter installed at a different insertion depth. In a few field installations, the meter could not be installed at the manufacturers recommended depth. As a result, some of the meters were inserted 1/4" too deep. A test

Figure 9: Test results from the 8" pipe. These results show the performance of the magnetic and non-magnetic meters with the manufacturers pulse per gallon (PPG) factor and the experimentally derived PPG factor.



* Non-magnetic Meter + Magnetic Meter □ Mag Meter Corrected

run under similar conditions produced results that indicate that there is no measurable change in recorded velocities. As can be seen in Figure 10 the results from the over-inserted meter were within $\pm 5\%$ of the flow rate. As expected, the general trend does appear to show that the velocities were slightly higher for the over-inserted meter but since the values are still within the measured accuracy, it is not significant enough to try and change the PPG factor. An over insertion of greater than 1/4" would likely produce a more significant difference but at this point, the meters in the field are installed within the tested range.

During the 8" testing, there was an unusual drop in the velocity recorded by the meters at 6 fps. The meter recorded a flow rate of almost 1 fps lower than the value should have been. This outlying point was also observed in the 6" pipe at 9 fps. After trying several different combinations of pumps and noting the results from each different combination, it was discovered that there was uneven flow mixing when a specific combination of pumps was used. Further review of the rotation tests in the 6" pipe also confirmed this. To correct the matter, a perforated plate type flow conditioner was installed at the supply end of the test section. This appeared to rectify the problem.

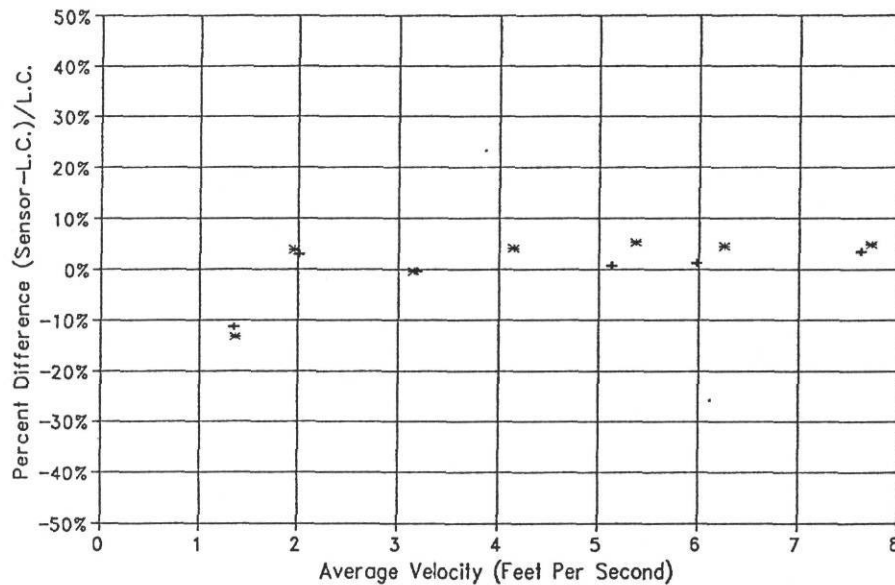
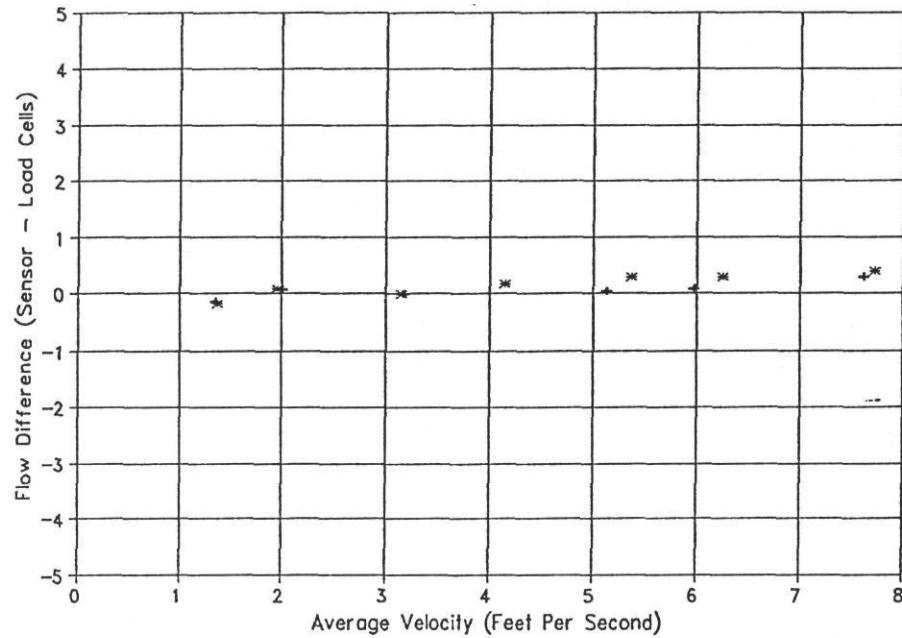
While the 8" test section was installed, the orifice plate was installed as the secondary standard. The initial test of the orifice was of great interest because it would determine whether or not the load cells were as accurate as they were thought to be. A series of tests were run using the specified orifice plate at each volumetric flow rate. As seen in Figure 11, the results were outstanding. The orifice plate was within $\pm 2\%$ of the flow rate over the full range of the system and in most cases, was within $\pm 1\%$ of the flow rate. The results are presented in volumetric form (gpm) rather than velocity because the volumetric rate is a function only of the pump combinations, not the pipe size of the test section. These results were very encouraging as they validated the testing that had been performed up to that point.

SECTION IV

10" Test Section

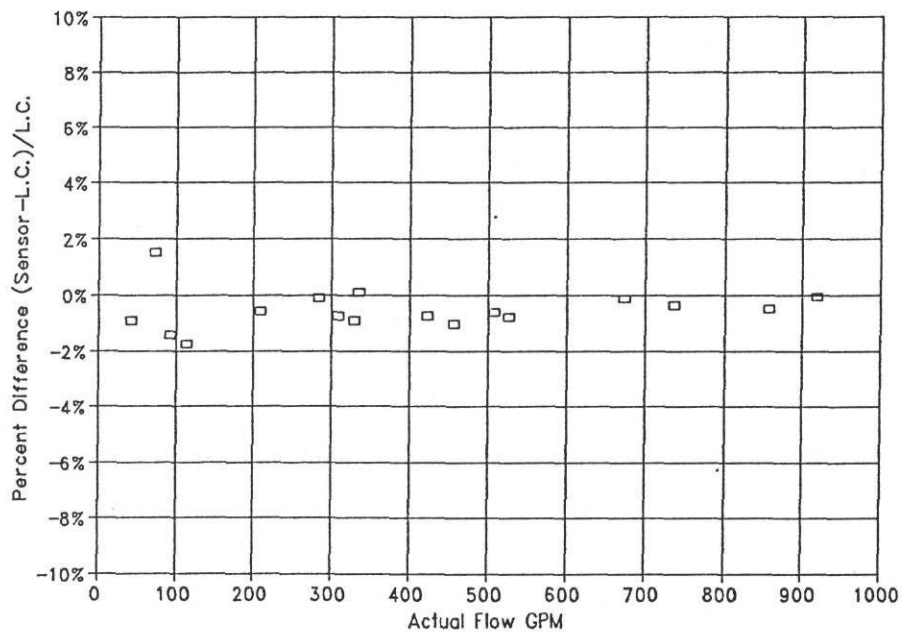
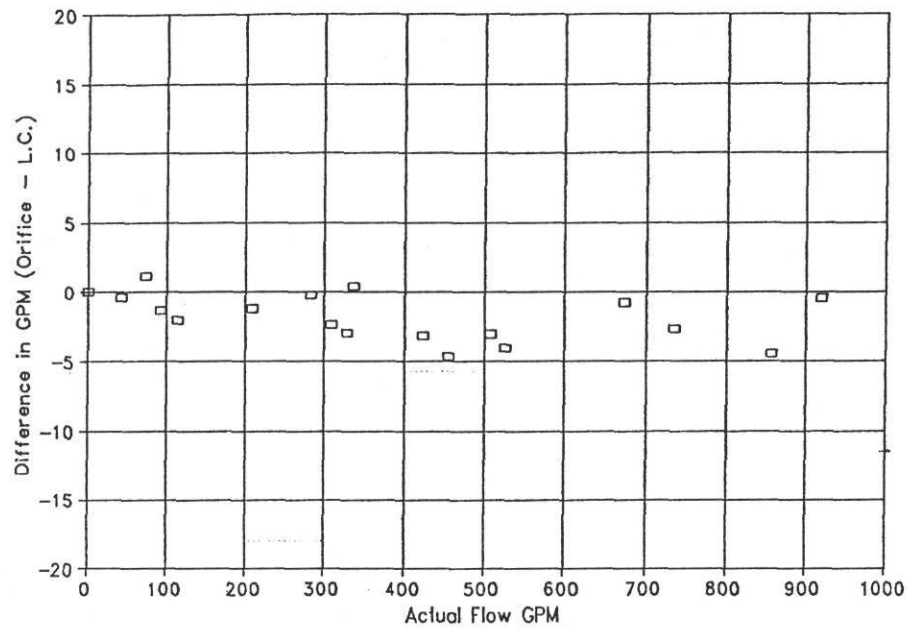
The testing in the 10" test section is limited by the capacity of the pumps to a maximum velocity of 5 fps. This does not enable the comprehensive testing that was possible on the

Figure 10: *Test results from the change in insertion depth of the non-magnetic meter in the 8" pipe. These results show the performance of the meter at the proper insertion depth of 1.5" and the over inserted depth of 1.75".*



+ 1.5" ID * 1.75" ID

Figure 11: *Test results from the orifice plate.* These results show the performance of the orifice plate (secondary standard) as compared to the load cells (primary standard).



6" and 8" sections. However, there are only a few instances in the field where the velocities in 10" pipes are higher than the maximum velocity achievable in the lab. The magnetic meter was again run through a series of tests to determine if the published PPG factor was correct. The results presented in Figure 12, show the flow meter to be recording velocities that were 7-8% lower than the load cells. A correction in the PPG factor and subsequent tests reduced that difference to an average of -2.5% of the flow rate. The fact that the PPG factor was off by 7% rather than 15% as seen in the previous two pipe sizes was a mystery. It was hoped that some sort of pattern could be developed so that the corrections could be estimated for all pipe sizes larger than 10". The 10" pipe is the maximum diameter test section that can be tested effectively in the lab and there are several field installations that have pipes 12" or larger. The encouraging result is that as the pipe size increases, the PPG factor decreases. Fractions cannot be used in the PPG factor so as the factor gets smaller, the chances of the published factor rounding down to the same number that our empirical PPG factor is rounding up to increases. Thus, it is anticipated that for the large pipes, the factor is close to being correct.

The non-magnetic meter again performed very well, especially at the low velocities. As seen in Figure 12, for the velocity range of 1 to 5 fps, the meter was within 4% of the flow rate. Also, at flow rates below 1 fps, the meter continued to record flow rates that were -5% of the actual rate. At the lowest velocity tested, .5 fps, the meter was within -10% of the actual rate.

The final series of tests performed in the 10" test section tested a third type of meter used in the monitoring project, an axial turbine insertion meter. This meter, as in the other insertion meters, is installed with a 2" hot tap in the pipe. The flow is measured with a turbine that has the axis parallel with the flow through the pipe. Power is supplied to the meter and a digital pulse is produced by the meter as the turbine rotates. The results from these tests, presented in Figure 13 were very good. The meter recorded velocities that were within -3% of the flow rate with an average difference over the entire range of -2%. The meter also continued to perform well down to 1 fps (the low end stated by the manufacturer). The only drawback of this particular meter is that it is approximately three times the cost of the paddlewheel meters.

Figure 12: Test results from the 10" pipe. These results show the performance of the magnetic and non-magnetic meters with the manufacturers pulse per gallon (PPG) factor and the experimentally derived PPG factor.

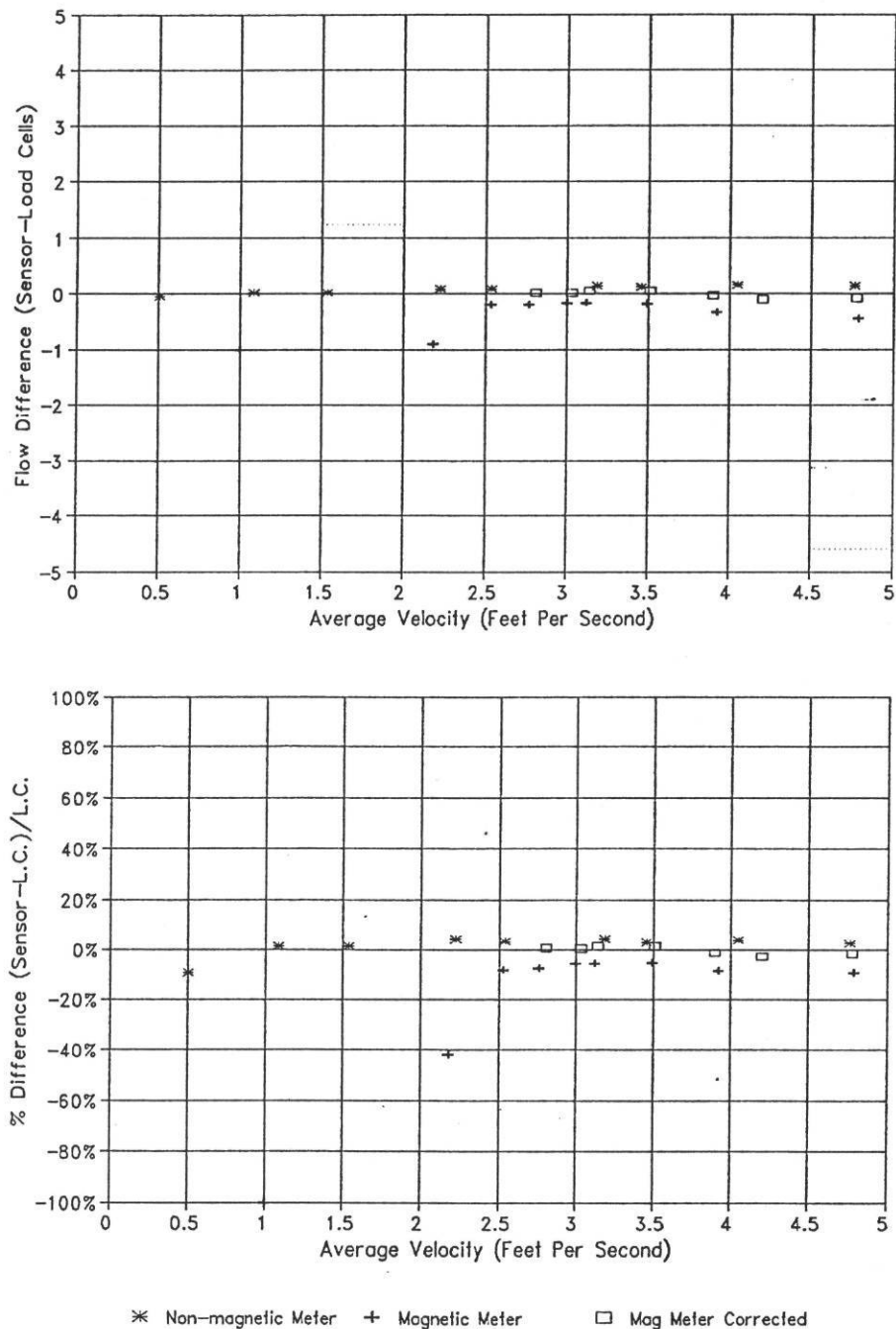
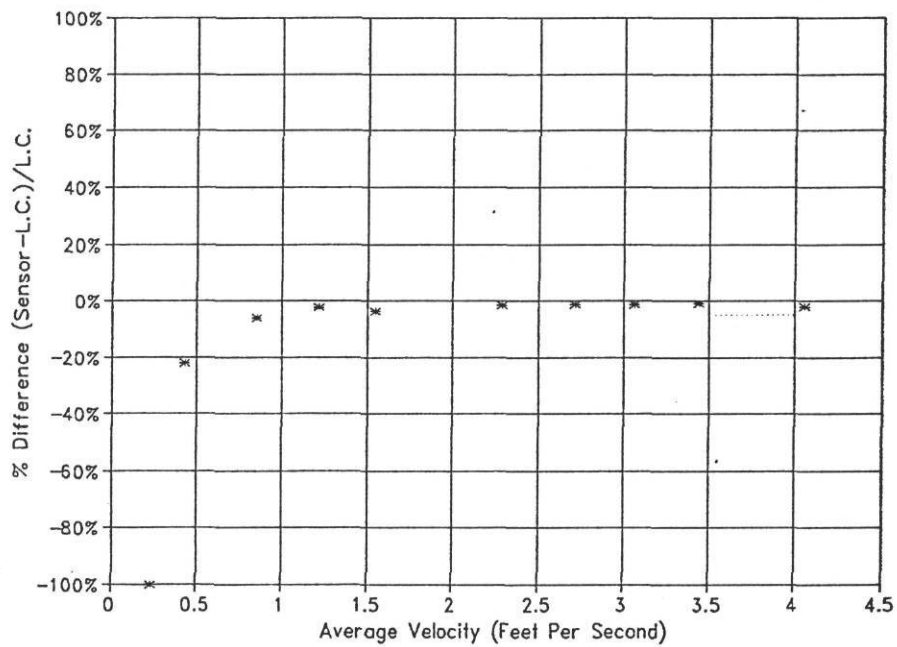
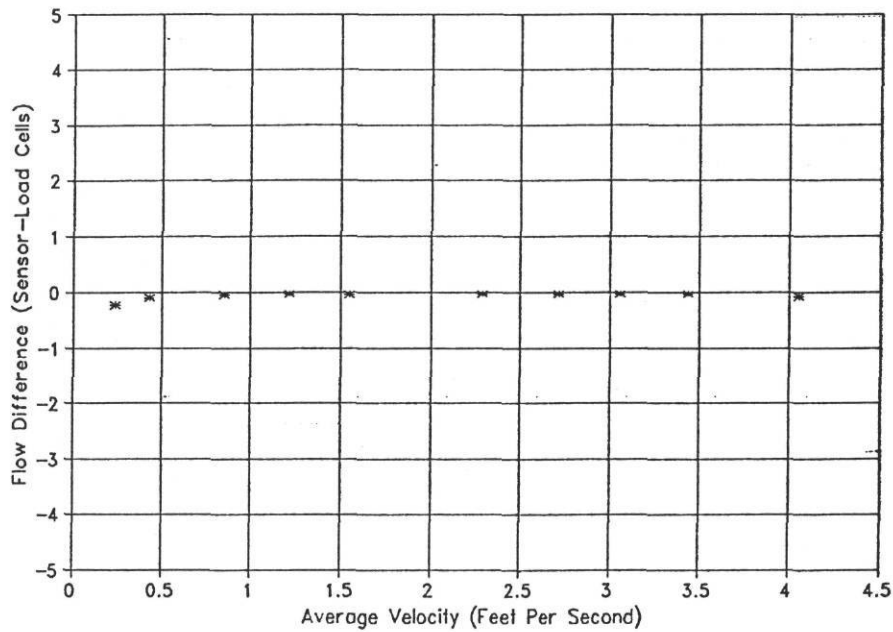


Figure 13: *Test results from the axial turbine insertion meter.* These results show the performance of the axial turbine meter in the 10" pipe as compared to the load cells.



SECTION V

4" Test Section

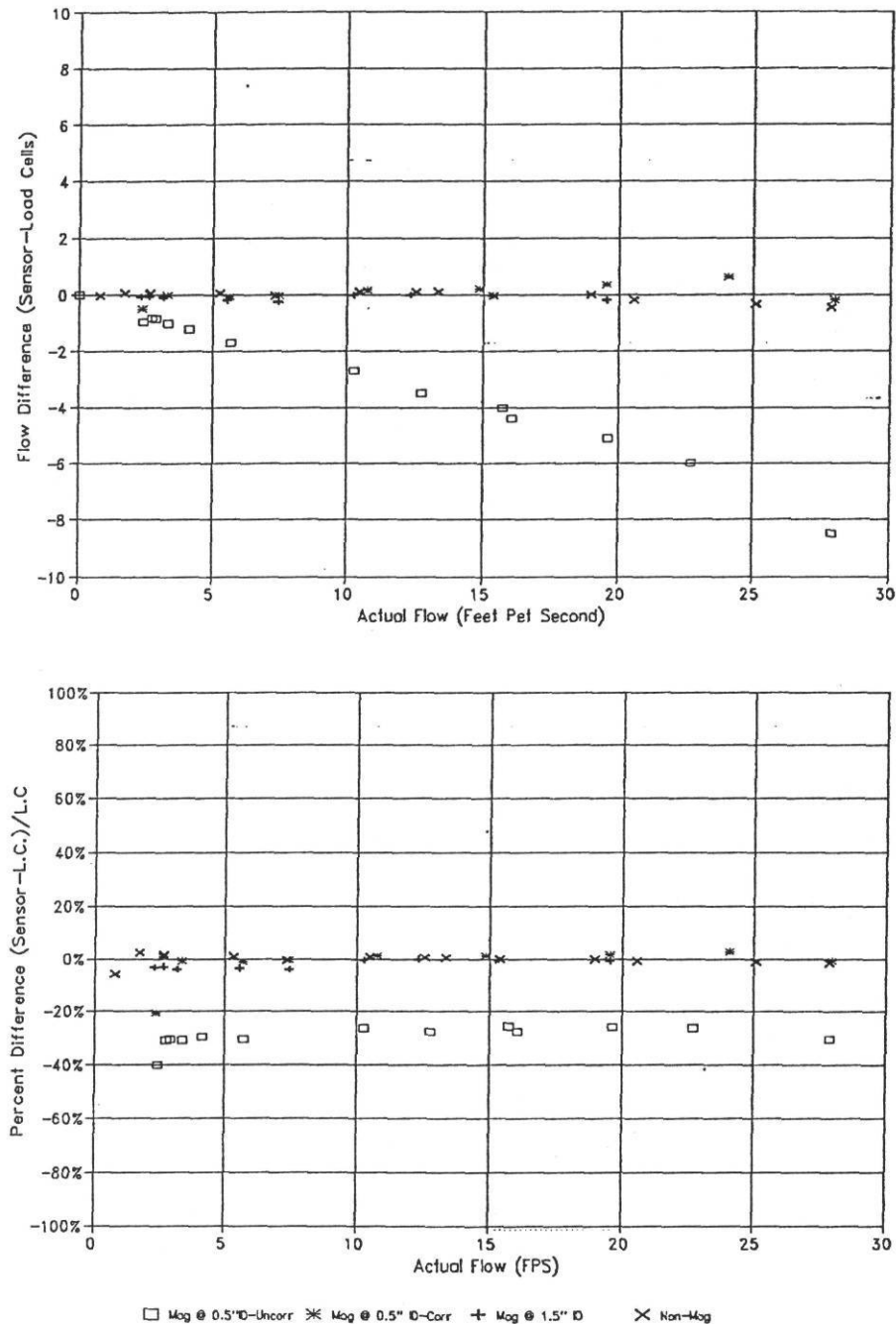
The 4" test section provided the most comprehensive testing of both meters. Velocities ranging from .5 fps to 28 fps were tested. This is the only section in which both meters could be tested over their advertised flow range of 1-30 fps.

There were some initial discrepancies about the proper insertion depth for the magnetic meter. Two sets of literature were found, one specifying 1/2" and the other specifying 1.5". As a result, both depths were tested. The 1/2" depth was tested first because it is the depth of insertion being used in the field installations using 4" pipe. The results presented in Figure 14 show that the recorded velocity of the meter was an average of 28% lower than the actual load cell velocity. After changing the PPG factor and re-testing, the average error was reduced to less than $\pm 2\%$ of the flow rate. This is a very good result considering the wide range of the velocity. The low end threshold of the magnetic meter in the 4" section was 2.5 fps.

The meter was then reset at an insertion depth of 1.5" and tested using the published PPG factor. The results from this test as seen in Figure 14, show that the meter readings were within $\pm 4\%$ of the actual velocity. One note of significance from this test is that there is not only a low end threshold, but also a high end threshold. At velocities above 20 fps, the Btu meter did not effectively receive the signal from the flow meter. The number of pulses produced by the flow meter were so high, the Btu meter did not pick up all of them. This did not occur for the insertion depth of .5" because the local velocity at a point close to the wall is lower than the local velocity at a point near the centerline, so the paddlewheel does not rotate as fast. This will not affect the monitoring project because there are no installations with velocities in this range. However, this means that when used in combination with this Btu meter which is a common arrangement, the flow range for the flow meter is 2 to 20 fps. The advertised flow range for this meter is 1-30 fps, thus only 2/3 of the advertised range is available in the 4" pipe. Also of interest was the low end threshold was 2 fps with the 1.5" insertion depth. This is an improvement of .5 fps over the .5" insertion depth. Again, this is due to the local velocity and where the meter is installed in the velocity profile.

The non-magnetic meter performed extremely well in the 4" test section. The results, also presented in Figure 14, show that it recorded velocities within $\pm 2\%$ for velocities above 2 fps. This is by far the best result for either of the meters in any of the pipe sizes. Below 2

Figure 14: Test results from the 4" pipe. These results show the performance of the magnetic and non-magnetic meters with the manufacturers pulse per gallon (PPG) factor and the experimentally derived PPG factor.



fps, the meter was within $\pm 5\%$ of the flow rate. Again, this meter does well in the low flow situations.

SECTION VI

Performance of Field Meters

The process of testing meters from the field installations has recently begun. Some of the meters have been in place for two years while the flowloop has been gearing up for the task. The initial accuracy of these meters has been determined by the tests run in the lab in the different pipe sizes. However, there is no way of knowing whether the meters in the field are still performing adequately until they are pulled and tested. Over the last several months, meters have been pulled and are in the process of being tested for comparison against new meters. The magnetic meters are the only ones being tested this point because the non-magnetic meters have not yet been in the field for a year.

The meters are being removed from a wide range of pipe sizes and, ideally, it might seem prudent to test each meter in the test section of the same size as the pipe the from which the meter was removed. However, this process would be virtually impossible because of the time and difficulty in changing out the test sections. Instead, each meter is being tested in the 4" pipe. Since the performance of a typical meter in each different pipe size is known, it is only necessary to determine if the performance of the meter has degraded since it was first installed. The 4" section was chosen because more tests can be run per tank than in the other sections. This enables the testing of the meters to proceed quickly. Each meter is inserted into the pipe in the exact condition from which it was pulled from the field. Most of the magnetic meters have a build-up of rust on the paddlewheels and some have large chunks of rust on the meter. The performance of the meter in this condition is then compared to a typical new meter to determine the amount of degradation. A simple three point test is run and then the meter is removed and cleaned. A second three point test is completed with the clean meter and it is then ready to be reinstalled at a new field location. When the same meter (tracked by serial number) is brought in for post calibration from its new site, the performance can be compared directly to the performance immediately prior to its installation.

So far, half a dozen meters have been calibrated in this manner. and the results have been very encouraging. All of the meters tested in their removed state (dirty) have been within

$\pm 4\%$ of the lab standard meter. Anything under 5% is considered as no change because the overall accuracy of the meters is $\pm 5\%$. Upon cleaning and re-testing, the meters show a slight increase in performance of about 1% in most cases. This is so small that it too is considered negligible.

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